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The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide: Addendum

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The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide: Addendum

by

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Research Triangle Park, NC 27711

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SECTION 1

INTRODUCTION

Under the Clean Air Act, the U.S. Environmental Protection Agency (EPA) is responsible for establishing National Ambient Air Quality Standards (NAAQS) and for reviewing them periodically to determine their adequacy on the basis of recent scientific research. In view of these responsibilities, the Strategies and Air Standards Division (SASD) of the Office of Air Quality Planning and Standards (OAQPS) is developing quantitative methods for assessing health risks associated with proposed air quality standards.

An important aspect of health risk assessment is the estimation of population exposure. For the past few years, SASD has been engaged in the development of an exposure model suitable for evaluating alternative ambient air standards. The model is known as NEM, an acronym for NAAQS Exposure Model.

Several versions of NEM have been developed. The exposure district version of NEM simulates the pollutant concentrations expected to occur in selected exposure districts within a study area under user-specified regulatory scenarios. It then adjusts these estimates to account for an exhaustive set of microenvironments and simulates typical movements of population groups, called cohorts, through the districts and microenvironments. Outputs of the simulation program are population exposure estimates at specified pollutant levels.

Another version of NEM substitutes "neighborhood types" for exposure districts. A 1983 report[1] described this neighborhood type (NT) model and its application to four U.S. urban areas (Chicago, IL, St. Louis, MO-IL, Philadelphia, PA, and Los Angeles, CA) to estimate population exposures associated with alternative NAAQS proposed for carbon monoxide (CO).

Computer outputs from NEM provide estimates of population exposure for various measures of exposure and averaging times. In the case of CO, NEM also estimates carboxyhemoglobin (COHb) levels, an important indicator of the physiological effects of CO on the exposed population. In this addendum to

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the 1983 report, results of NEM analyses of CO exposure in four study areas under two air quality assumptions are compared. The first assumption is that an air quality standard of 9 ppm with one expected exceedance (9 ppm 1 ExEx) is met in all four study areas. This assumption was used in previous reported analyses.[1] The second assumption is that an air quality standard of 9 ppm with one observed exceedance is met in all study areas. The difference is that the first form of standard is based on the characteristic high, an air quality indicator statistically derived from daily maximum 8-hour values, while the second standard is based on the second highest 8-hour running average observed during the year. Note that a complete year of data contains 365 daily maximum 8-hour values versus nearly 8760 8-hour running average values. Note that some "observed" values are estimates based on the time series model used in NEM analyses. Table 1-1 lists the air quality indicators used for roll-back purposes under each form of the standard.

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TABLE 1-1. AIR QUALITY INDICATORS FOR 8-HOUR CARBON MONOXIDE STANDARD WITH ONE EXPECTED EXCEEDANCE OF 9 ppm PER YEAR AND WITH ONE OBSERVED EXCEEDANCE OF 9 ppm PER YEAR

Study area	NT	Air quality indicator, ppm: Expected exceedance standard[a]	Air quality indicator, ppm: Observed exceedance standard[b]
Chicago	CR	7.2	7.5
	CC	15.6	15.9
	CI	10.8	10.6
	SR	9.5	12.2
	SC	10.0	12.2
	SI	8.3	9.5
Los Angeles	CR	8.8	9.0
	CC	20.1	18.1
	CI	20.3	21.7
	SR	15.5	13.6
	SC	16.6	15.6
	SI	20.3	21.7
Philadelphia	CR	14.3	18.3
	CC	14.3	18.3
	CI	7.2	11.4
	SR	7.9	8.3
	SC	7.9	8.3
	SI	10.4	11.7
St. Louis	CR	6.1	6.7
	CC	10.7	11.1
	CI	14.7	14.4
	SR	12.5	14.0
	SC	11.5	10.2
	SI	14.7	14.4

[a]Characteristic largest value estimated from distribution fit to daily maximum 8-hour values.

[b]Second highest observed 8-hour running average value.

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SECTION 2

EXPOSURE ESTIMATES FOR ADULTS WITH CARDIOVASCULAR DISEASE IN FOUR URBAN AREAS

Exposure estimates presented in this report are for adults with cardiovascular disease. Adults are defined to be persons at least 18 years old. Based on the currently available evidence, this subpopulation is judged to be the most sensitive group of persons with respect to CO-induced adverse health effects. As indicated on page 7-34 of the 1983 report,[1] the values used for the percentage of adult females with cardiovascular disease was 4.2 percent and for adult males 5.8 percent. These values are based on the U.S. Department of Health, Education, and Welfare data[2] on coronary heart disease and, contrary to the statement on page 7-1 of the 1983 report,[1] these estimates do not include individuals with peripheral vascular disease.

2.1 "BEST ESTIMATE" RESULTS

Tables 2-1 through 2-9 contain selected printouts of a NEM analysis of exposure of adults with cardiovascular disease to CO in the four study areas under various air quality assumptions. Each table is identified as to CO/COHb indicator and air quality standard being simulated. CO exposure estimates are provided for both 1- and 8-hour average CO concentrations. In each case, the "best-estimate" microenvironment factors developed in Section 6 of the 1983 report[1] were used to simulate the contribution of gas stoves and smoking to total CO exposure. Tables 2-1 through 2-9 are exactly analagous to Tables 7-1 through 7-9 of the 1983 report (pages 7-2 to 7-10) because the conditions specified are exactly the same except that a different form of NAAQS is used.

2.1.1 Attainment of 9 ppm/1 ObEx Standard

NEM estimates in Tables 2-1 through 2-9 were developed by adjusting the air quality data for each study area using the roll-back formula described in Section 5.1 of the 1983 report[1] so that the most polluted neighborhood type just meets a 9 ppm - 8 hour average - 1 observed exceedance (9 ppm/1 ObEx)

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TABLE 2-1. ESTIMATES OF OCCURRENCES FOR ADULTS WITH CARDIOVASCULAR DISEASE OF 1-HOUR CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION EXCEEDED (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				709
25.0	524		1,280	6,910
20.0	24,600	5,790	1,280	16,600
15.0	212,000	97,400	33,100	41,800
12.0	746,000	849,000	141,000	241,000
9.0	2,960,000	4,830,000	441,000	881,000
7.0	9,760,000	14,800,000	1,320,000	3,070,000
0.0	1,070,000,000	2,670,000,000	1,020,000,000	416,000,000
MAX. CONCENTRATION	25.1	20.5	28.0	32.5
ENCOUNTERS AT MAX.	523	5,790	1,270	707

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TABLE 2-2. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHO HAVE 1-HOUR CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION EXCEEDED (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				707
25.0	523		1,270	6,200
20.0	11,400	5,790	1,270	10,400
15.0	22,300	49,300	23,000	21,000
12.0	53,200	167,000	36,800	28,800
9.0	109,000	248,000	69,300	36,600
7.0	121,000	298,000	91,100	44,800
0.0	122,000	305,000	116,000	47,500
MAX. CONCENTRATION	25.1	20.5	28.0	32.5
PEOPLE AT MAXIMUM	523	5,790	1,270	707

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TABLE 2-3. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHOSE MAXIMUM 1-HOUR CO EXPOSURE OCCURS IN SELECTED CONCENTRATION RANGES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION RANGE (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0 < C <= 100.0				
55.0 < C <= 60.0				
50.0 < C <= 55.0				
45.0 < C <= 50.0				
40.0 < C <= 45.0				
35.0 < C <= 40.0				
30.0 < C <= 35.0				709
25.0 < C <= 30.0	524		1,280	5,490
20.0 < C <= 25.0	10,900	5,790		4,190
15.0 < C <= 20.0	10,900	43,500	21,700	10,700
12.0 < C <= 15.0	30,900	118,000	13,800	7,730
9.0 < C <= 12.0	55,500	80,800	32,500	7,850
7.0 < C <= 9.0	12,400	50,500	21,800	8,160
0.0 < C <= 7.0	494	6,890	25,200	2,730
MAX. CONCENTRATION	25.1	20.5	28.0	32.5
PEOPLE AT MAXIMUM	523	5,790	1,270	707

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TABLE 2-4. ESTIMATES OF OCCURRENCES FOR ADULTS WITH CARDIOVASCULAR DISEASE OF 8-HOUR CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION EXCEEDED (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				
25.0				
20.0				
15.0				
12.0				
9.0	78,700	80,100	66,700	81,100
7.0	1,840,000	1,370,000	422,000	473,000
(0	1,070,000,000	2,670,000,000	1,020,000,000	416,000,000
MAX. CONCENTRATION	11.6	10.1	11.0	11.6
ENCOUNTERS AT MAX.	120	2,000	29	11

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TABLE 2-5. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHO HAVE 8-HOUR CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION EXCEEDED (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				
25.0				
20.0				
15.0				
12.0				
9.0	5,260	5,790	20,300	15,000
7.0	67,100	65,100	35,400	24,400
0.0	122,000	305,000	116,000	47,500
MAX. CONCENTRATION	11.6	10.1	11.0	11.6
PEOPLE AT MAXIMUM	120	2,000	29	11

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TABLE 2-6. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHOSE MAXIMUM 8-HOUR CO EXPOSURE OCCURS IN SELECTED CONCENTRATION RANGES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

CONCENTRATION RANGE (PPM)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
60.0 < C <= 100.0				
55.0 < C <= 60.0				
50.0 < C <= 55.0				
45.0 < C <= 50.0				
40.0 < C <= 45.0				
35.0 < C <= 40.0				
30.0 < C <= 35.0				
25.0 < C <= 30.0				
20.0 < C <= 25.0				
15.0 < C <= 20.0				
12.0 < C <= 15.0				
9.0 < C <= 12.0	5,270	5,790	20,300	15,000
7.0 < C <= 9.0	61,900	59,300	15,200	9,430
0.0 < C <= 7.0	54,400	240,000	80,900	23,100
MAX. CONCENTRATION	11.6	10.1	11.0	11.6
PEOPLE AT MAXIMUM	120	2,000	29	11

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TABLE 2-7. ESTIMATES OF OCCURRENCES FOR ADULTS WITH CARDIOVASCULAR DISEASE OF COHb LEVELS EXCEEDING SELECTED VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

COHB LEVEL EXCEEDED (PERCENT)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
7 70				
3.50				
3.30				
3.10				
3.00				
2.90				
2.70				
2.50				
2.30				
2.10				
2.00				21
1.50	66,400	49,400	43,400	58,700
1.00	7,820,000	13,900,000	1,070,000	2,140,000
0.00	1,070,000,000	2,670,000,000	1,020,000,000	416,000,000
MAX. COHB CONC.	1.89	1.78	1.86	2.05
ENCOUNTERS AT MAX.	54	1,560	15	5

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TABLE 2-8. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHO EXPERIENCE COHb LEVELS EXCEEDING SELECTED VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

COHB LEVEL EXCEEDED (PERCENT)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
3.70				
3.50				
3.30				
3.10				
3.00				
2.90				
2.70				
2.50				
2.30				
2.10				
2.00				21
1.50	9,160	5,790	15,500	16,700
1.00	94,200	232,000	40,300	35,000
0.00	122,000	305,000	116,000	47,500
MAX. COHB CONC.	1.89	1.78	1.86	2.05
PEOPLE AT MAXIMUM	54	1,560	15	5

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TABLE 2-9. ESTIMATES OF ADULTS WITH CARDIOVASCULAR DISEASE WHOSE MAXIMUM COHb LEVEL OCCURS IN SELECTED RANGES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

COHB LEVEL RANGE (PERCENT)	CHICAGO	LOS ANGELES	PHILADELPHIA	ST LOUIS
3.70 < C <= 10.00				
3.50 < C <= 3.70				
3.30 < C <= 3.50				
3.10 < C <= 3.30				
3.00 < C <= 3.10				
2.90 < C <= 3.00				
2.70 < C <= 2.90				
2.50 < C <= 2.70				
2.30 < C <= 2.50				
2.10 < C <= 2.30				
2.00 < C <= 2.10				21
1.50 < C <= 2.00	9,160	5,790	15,500	16,700
1.00 < C <= 1.50	85,000	227,000	24,800	18,300
0.00 < C <= 1.00	27,400	72,800	76,000	12,500
MAX. COHB CONC.	1.89	1.78	1.86	2.05
PEOPLE AT MAXIMUM	54	1,560	15	5

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standard, i.e., one specifying that the number of 8-hour running average CO values exceeding 9 ppm shall not be greater than 1 per year. Table 2-1 provides estimates of the number of occurrences for adults with cardiovascular disease of 1-hour exposures to CO concentrations exceeding selected values. (Exposures exactly equal to zero are counted as exceeding zero.) Thus, each column in Table 2-1 presents a cumulative frequency distribution in which the number of 1-hour exposures increases as CO concentration decreases; the distribution reaches a maximum at a CO concentration of zero. This maximum is the number of adults with cardiovascular disease used in the simulation times the number of possible occurrences in a year (8760). Although NEM yields individual frequency distributions for cohorts who are at low, medium, and high activity levels when a given CO concentration is encountered, only the total frequency distribution for all activity levels is presented in Table 2-1. According to these estimates, none of the four study areas would have more than 6,910 occurrences of 1-hour CO exposures above 25 ppm if a 9 ppm/1 ObEx standard were just attained. This statement is also true for the 9 ppm/1 ExEx standard, as shown in Table 7-1 in the 1983 report.[1]

Table 2-2 uses an alternative exposure indicator, adults with cardiovascular disease with 1-hour exposures. This is the number of adults with cardiovascular disease in the study area that experience one or more 1-hour exposures per year to CO concentrations that exceed a specified value. This exposure indicator is also expressed as a cumulative frequency distribution. The number of adults with cardiovascular disease exposed at zero concentration (or above) is the total population of the study area.

Table 2-3 provides estimates of the number of adults with cardiovascular disease who experience their peak exposure of the year within selected intervals of 1-hour CO concentrations. These estimates are not cumulative; each peak exposure falls within a single interval.

Tables 2-4 through 2-6 are similar to Tables 2-1 through 2-3 except that exposures are estimated in terms of 8-hour running average CO concentrations. Because the average of any eight successive hourly concentrations is less than or equal to the highest value in the series, pollutant exposures usually occur at lower concentrations for 8-hour running averages than for 1-hour averages. For example, the maximum 8-hour running average concentration experienced in Chicago is 11.5 ppm (Table 2-4), while the maximum 1-hour concentration is

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25.1 ppm (Table 2-1). Similarly, the number of 8-hour running average exposures above 9 ppm is 78,700 in Table 2-4, compared with 2,960,000 1-hour average exposures in Table 2-1.

The 1983 report[1] lists the general algorithm used by NEM to estimate COHb levels in the exposed populations. Full documentation of the rationale for the choice of these values is provided in an EPA memorandum referenced in that report. In essence, the carboxyhemoglobin algorithm estimates the COHb levels of an individual at the end of every hour of the year. Although COHb levels are, strictly speaking, the result of CO exposure, they can be described using concepts similar to those used for CO exposure. For example, Table 2-7 lists the number of occurrences of COHb levels that exceed selected values. Table 2-8 lists the number of adults with cardiovascular disease that experience COHb levels which exceed selected values. Table 2-9 lists the number of adults with cardiovascular disease who experience their highest COHb level within selected ranges of COHb values. As would be expected, Tables 2-7 and 2-8 present cumulative distributions, while Table 2-9 lists results in discrete intervals.

The relative frequencies of high COHb levels among the four study areas can be compared by normalization, i.e., by converting the estimates of adults with cardiovascular disease experiencing different COHb levels to the corresponding percentage of total adults with cardiovascular disease in the study area population. Table 2-10 shows that none of the study areas have adults with cardiovascular disease with COHb levels exceeding 2.1 percent under the 9 ppm/1 ObEx standard. Approximately 13.4 percent of the Philadelphia adults with cardiovascular disease experience COHb levels exceeding 1.50 percent. Maximum COHb levels are 1.89 percent for Chicago, 1.78 percent for Los Angeles, 1.86 percent for Philadelphia, and 2.05 percent for St. Louis.

As previously noted, the estimates presented in the tables are for adults with cardiovascular disease. The value used for the percentage of adult females with cardiovascular disease was 4.2 percent; for adult males the value was 5.8 percent. These values are identical to those used in the 1983 report. In this application of NEM, estimates for the whole population were ratioed down to the estimates for adults with cardiovascular disease by using these two values in conjunction with estimates of the percentages of adults who are male and female in each of the four cities (52% female and 48%

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TABLE 2-10. PERCENTAGE OF ADULTS WITH CARDIOVASCULAR DISEASE EXPERIENCING COHb LEVELS EXCEEDING SELECTED VALUES ASSUMING 9 PPM/1 OBEX STANDARD IS ATTAINED

COHb level exceeded (percent)	Chicago	Los Angeles	Philadelphia	St. Louis
3.00				
2.90				
2.80				
2.70				
2.60				
2.50				
2.40				
2.30				
2.10				
2.00				0.04
1.50	7.51	1.90	13.36	35.16
1.00	77.21	76.07	34.74	73.68
0.00	100.00	100.00	100.00	100.00
Max. COHb conc.	1.89	1.78	1.86	2.05
Percent at maximum	0.20	2.14	0.02	0.04

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male). The fact that all married women are females was accounted for in the calculation, but the fact that the male/female percentage breakdown varies from one occupation to another was not.

The estimates use 1980 census data for the four cities but are projected to 1987 by using the multiplicative factor 1.195. The development of this factor is explained in the 1983 report.[1]

2.2 THE SIGNIFICANCE OF INDOOR SOURCES

Exposure estimates discussed in Section 2.1 assumed gas stoves and smoking contribute to total CO exposure. The significance of these CO sources was analyzed in Section 7.3 of the 1983 report.[1] Maximum 1-hour CO exposures were found to be less than 1.0 percent higher when indoor sources were included in the analysis. Maximum 8-hour CO exposures were found to be 1.0 to 7.7 percent higher when indoor sources were included. In the NEM model, peak CO levels are generally experienced in transportation vehicles or along roadways--microenvironments with "best-estimate" multiplicative factors of 2.10 and 1.20, respectively.

2.3 UNCERTAINTY IN NEM EXPOSURE ESTIMATES

Any method used to estimate exposure of large, diverse groups of people must deal with uncertainties in data and in assumptions used. The exposure model can only represent major features. Because the relevant data bases are often incomplete and/or inaccurate, professional judgment plays a significant role in selecting monitors to represent neighborhood types, in validating air quality data, in estimating cohort populations, and in determining cohort movements. Lower, best, and upper estimates of microenvironmental factors were presented in Section 6.0 of the 1983 report.[1] The results of analyzing these factors indicate that the difference between the lower estimates and the upper estimates is appreciable. This large variation primarily results from the large differences between lower and upper estimates of multiplicative microenvironment factors, particularly those for transportation vehicles and roadsides.

A limited sensitivity analysis was conducted on two of the physiological variables which determine COHb levels in the blood resulting from given

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patterns of CO exposure. Variations in the Haldane constant and ventilation rates have a significant effect, but not as large an effect as the variation in estimated microenvironment factors. Details of these analyses were given in the 1983 report.[1]

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SECTION 3

NATIONWIDE EXTRAPOLATIONS

Section 2 summarizes the results of applying NEM to four study areas, namely, Chicago, Los Angeles, Philadelphia, and St. Louis. Rough estimates of national exposure for adults with cardiovascular disease were made by extrapolating these exposure and COHb estimates. The extrapolation procedure is described in Section 8 of the 1983 report.[1]

3.1 EXTRAPOLATION RESULTS

The results of the nationwide extrapolation are presented in Tables 3-1 through 3-10. The first nine tables can be divided into three sets of three tables. Tables 3-1, 3-2, and 3-3 present exposure estimates for a 1-hour averaging time. Estimates of occurrences during 1987 among adults with cardiovascular disease of 1-hour average CO exposures above selected concentration values under four alternative air quality assumptions are presented in Table 3-1. Estimates of the number of adults with cardiovascular disease in the urban U.S. who would incur 1-hour average CO exposures above the same set of selected concentrations under the same assumptions are presented in Table 3-2. Estimates of the number of urban U.S. adults whose maximum 1-hour average CO exposure would occur in various concentration ranges are presented in Table 3-3.

Analogous estimates for 8-hour average CO exposures are presented in Tables 3-4, 3-5, and 3-6, respectively. Similar estimates for COHb levels resulting from CO exposure are presented in Tables 3-7, 3-8, and 3-9. The absolute numbers presented in Table 3-9 are presented in percentage form in Table 3-10.

Estimates of the number of adults with cardiovascular disease who would have their blood COHb levels elevated above selected concentrations for various numbers of days if an 8-hour average 9 ppm/1 ExEx standard were just met in all urban areas are presented in Table 3-8. The table indicates the

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TABLE 3-1. ESTIMATES OF OCCURRENCES IN THE CARDIOVASCULAR ADULT URBAN U.S. POPULATION OF 1-HOUR AVERAGE CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION EXCEEDED (PPM)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0				10,200
55.0				21,900
50.0				21,900
45.0			10,200	33,600
40.0			21,900	359,000
35.0	10,200		124,000	849,000
30.0	21,900	11,700	359,000	2,140,000
25.0	168,000	134,000	1,700,000	6,310,000
20.0	915,000	778,000	6,570,000	21,300,000
15.0	6,620,000	5,410,000	31,300,000	78,700,000
12.0	27,700,000	22,700,000	88,500,000	185,000,000
9.0	102,000,000	93,700,000	296,000,000	602,000,000
7.0	370,000,000	306,000,000	873,000,000	1,640,000,000
0.0	45,900,000,000	45,900,000,000	45,900,000,000	45,900,000,000
MAX. CONCENTRATION ENCOUNTERS AT MAX.	36.0 10,200	32.5 11,700	49.0 10,200	61.5 10,200

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TABLE 3-2. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. WITH 1-HOUR AVERAGE CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION EXCEEDED (PPM)	9 PPM 8HR 1EXEX	9 PPM 8HR 10SEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0				10,200
55.0				21,900
50.0				21,900
45.0			10,200	21,900
40.0			21,900	348,000
35.0	10,200		113,000	531,000
30.0	21,900	11,700	348,000	872,000
25.0	157,000	123,000	691,000	1,270,000
20.0	535,000	423,000	1,290,000	2,510,000
15.0	1,290,000	1,150,000	2,900,000	4,290,000
12.0	2,820,000	2,440,000	4,290,000	4,800,000
9.0	4,390,000	4,210,000	5,030,000	5,220,000
7.0	5,140,000	4,960,000	5,240,000	5,240,000
0.0	5,240,000	5,240,000	5,240,000	5,240,000
MAX. CONCENTRATION PEOPLE AT MAXIMUM	36.0 10,200	32.5 11,700	49.0 10,200	61.5 10,200

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TABLE 3-3. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. WHOSE MAXIMUM 1-HOUR AVERAGE CO EXPOSURE OCCURS IN SELECTED CONCENTRATION RANGES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION RANGE (PPM)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0 < C <= 100.0				10,200
55.0 < C <= 60.0				11,700
50.0 < C <= 55.0				
45.0 < C <= 50.0			10,200	
40.0 < C <= 45.0			11,700	326,000
35.0 < C <= 40.0	10,200		90,600	184,000
30.0 < C <= 35.0	11,700	11,700	235,000	341,000
25.0 < C <= 30.0	135,000	111,000	344,000	401,000
20.0 < C <= 25.0	378,000	300,000	603,000	1,240,000
15.0 < C <= 20.0	753,000	729,000	1,610,000	1,770,000
12.0 < C <= 15.0	1,530,000	1,290,000	1,390,000	510,000
9.0 < C <= 12.0	1,570,000	1,770,000	738,000	426,000
7.0 < C <= 9.0	747,000	745,000	211,000	18,600
0.0 < C <= 7.0	107,000	284,000	4,730	
MAX. CONCENTRATION	36.0	32.5	49.0	61.5
PEOPLE AT MAXIMUM	10,200	11,700	10,200	10,200

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TABLE 3-4. ESTIMATES OF OCCURRENCES IN THE CARDIOVASCULAR ADULT URBAN U.S. POPULATION OF 8-HOUR AVERAGE CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION EXCEEDED (PPM)	9 PPM 8HR 1EXEX	7 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				
25.0				
20.0				104,000
15.0			429,000	3,830,000
12.0	200,000		4,290,000	29,200,000
9.0	6,340,000	3,690,000	54,900,000	206,000,000
7.0	63,500,000	51,900,000	322,000,000	835,000,000
0.0	45,900,000,000	45,900,000,000	45,900,000,000	45,900,000,000
MAX. CONCENTRATION	14.0	11.5	18.5	23.0
ENCOUNTERS AT MAX.	232	2,480	232	232

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TABLE 3-5. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. WITH 8-HOUR AVERAGE CO EXPOSURES ABOVE SELECTED CONCENTRATION VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION EXCEEDED (PPM)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0				
55.0				
50.0				
45.0				
40.0				
35.0				
30.0				
25.0				
20.0				49,400
15.0			176,000	529,000
12.0	90,000		538,000	1,770,000
9.0	618,000	534,000	2,410,000	3,660,000
7.0	2,650,000	2,230,000	4,090,000	4,950,000
0.0	5,240,000	5,240,000	5,240,000	5,240,000
MAX. CONCENTRATION	14.0	11.5	18.5	23.0
PEOPLE AT MAXIMUM	232	2,480	232	232

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TABLE 3-6. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. WHOSE MAXIMUM 8-HOUR AVERAGE CO EXPOSURE OCCURS IN SELECTED CONCENTRATION RANGES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

CONCENTRATION RANGE (PPM)	9 PPM 8HR 1EXEX	9 PPM 8HR 10EEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
60.0 < C <= 100.0				
55.0 < C <= 60.0				
50.0 < C <= 55.0				
45.0 < C <= 50.0				
40.0 < C <= 45.0				
35.0 < C <= 40.0				
30.0 < C <= 35.0				
25.0 < C <= 30.0				
20.0 < C <= 25.0				49,400
15.0 < C <= 20.0			176,000	480,000
12.0 < C <= 15.0	98,100		362,000	1,240,000
9.0 < C <= 12.0	520,000	534,000	1,870,000	1,890,000
7.0 < C <= 9.0	2,030,000	1,700,000	1,680,000	1,290,000
0.0 < C <= 7.0	2,590,000	3,010,000	1,160,000	291,000
MAX. CONCENTRATION	14.0	11.5	18.5	23.0
PEOPLE AT MAXIMUM	232	2,480	232	232

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TABLE 3-7. ESTIMATES OF OCCURRENCES AMONG CARDIOVASCULAR ADULTS IN URBAN U.S. OF COHb LEVELS EXCEEDING SELECTED VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

COHB LEVEL EXCEEDED (PERCENT)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
3.70				637
3.50				6,690
3.30				15,300
3.10				51,800
3.00			570	106,000
2.90			2,650	250,000
2.70			14,800	810,000
2.50			76,700	1,880,000
2.30	570		473,000	4,100,000
2.10	12,000		1,580,000	8,580,000
2.00	41,700	350	2,730,000	13,900,000
1.50	4,730,000	2,780,000	38,300,000	151,000,000
1.00	296,000,000	248,000,000	1,070,000,000	2,270,000,000
0.00	45,900,000,000	45,900,000,000	45,900,000,000	45,900,000,000
MAX. COHB CONC. ENCOUNTERS AT MAX.	2.30 120	2.04 82	3.02 120	3.75 120

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TABLE 3-8. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. EXPERIENCING COHb LEVELS EXCEEDING SELECTED VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

COHB LEVEL EXCEEDED (PERCENT)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
3.70				345
3.50				3,200
3.30				6,600
3.10				25,800
3.00			281	58,200
2.90			1,250	132,000
2.70			6,230	308,000
2.50			42,000	506,000
2.30	281		217,000	732,000
2.10	5,500		452,000	1,060,000
2.00	22,200	346	660,000	1,350,000
1.50	742,000	598,000	2,100,000	3,480,000
1.00	4,140,000	3,620,000	5,090,000	5,180,000
0.00	5,240,000	5,240,000	5,240,000	5,240,000
MAX. COHB CONC.	2.30	2.04	3.02	3.75
PEOPLE AT MAXIMUM	120	82	120	120

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TABLE 3-9. ESTIMATES OF CARDIOVASCULAR ADULTS IN URBAN U.S. WHOSE MAXIMUM COHb LEVEL OCCURS IN SELECTED CONCENTRATION RANGES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

COHB LEVEL RANGE (PERCENT)	9 PPM 8HR 1EXEX	9 PPM 8HR 10BEX	12 PPM 8HR 1EXEX	15 PPM 8HR 1EXEX
3.70 < C <= 10.00				351
3.50 < C <= 3.70				2,860
3.30 < C <= 3.50				3,400
3.10 < C <= 3.30				19,200
3.00 < C <= 3.10			285	32,400
2.90 < C <= 3.00			972	74,100
2.70 < C <= 2.90			4,990	175,000
2.50 < C <= 2.70			35,900	198,000
2.30 < C <= 2.50	285		175,000	227,000
2.10 < C <= 2.30	5,230		235,000	327,000
2.00 < C <= 2.10	16,700	350	208,000	291,000
1.50 < C <= 2.00	720,000	598,000	1,440,000	2,130,000
1.00 < C <= 1.50	3,400,000	3,020,000	2,990,000	1,700,000
0.00 < C <= 1.00	1,100,000	1,630,000	149,000	63,000
MAX. COHB CONC.	2.30	2.04	3.02	3.75
PEOPLE AT MAXIMUM	120	82	120	120

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TABLE 3-10. PERCENTAGE OF CARDIOVASCULAR ADULT URBAN U.S. POPULATION EXPERIENCING COHb LEVELS EXCEEDING SELECTED VALUES UNDER ALTERNATIVE AIR QUALITY ASSUMPTIONS

COHb level exceeded (percent)	9 ppm 8 h 1 ExEx	9 ppm 8 h 1 ObEx	12 ppm 8 h 1 ExEx	15 ppm 8 h 1 ExEx
3.70				0.01
3.50				0.06
3.30				0.13
3.10				0.49
3.00			0.01	1.11
2.90			0.02	2.52
2.70			0.12	5.88
2.50			0.80	9.66
2.30	0.01		4.14	13.97
2.10	0.10		8.63	20.23
2.00	0.42	0.01	12.60	25.76
1.50	14.16	11.41	40.08	66.41
1.00	79.01	69.08	97.14	98.85
0.00	100.00	100.00	100.00	100.00

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frequency of repeated peak COHb levels. The table indicates, for example, that of the 5,500 adults with cardiovascular disease who are estimated to have their blood COHb level exceed 2.1 percent under the 9 ppm/1 ExEx standard, none would have it occur more than one day.

3.2 UNCERTAINTY OF NATIONWIDE ESTIMATES

The uncertainty in the CO exposure and COHb estimates for the four base cities was discussed in Section 2. The nationwide estimates are even more uncertain because of the additional uncertainty introduced by the extrapolation of exposure estimates for these four cities to all urban areas in the U.S. The analyses discussed in the 1983 report[1] indicated that uncertainty is already great at the city level. That even greater uncertainty exists in the nationwide estimates should be recognized when considering the estimates presented in Tables 3-1 through 3-10.

3.3 COMPARING TWO FORMS OF NAAQS

Two forms of NAAQS are listed in Tables 3-1 through 3-10, both defined at the 9 ppm level. The first form is the expected exceedance (ExEx) form whereby one exceedance is expected to occur during the year, according to a distribution fitting procedure. The second form is the observed exceedance (ObEx) form whereby one observed exceedance means one 8-hour value at a CO monitor exceeded the standard during the year.

Comparing exposure estimates under two forms of NAAQS in Tables 3-1 to 3-9 shows a rough similarity between the two distributions of exposure. For example, Table 3-1 shows 102,000,000 occurrences of 1-hour average exposure at 9 ppm or above under the 1 ExEx form of NAAQS and 93,700,000 occurrences under the 1 ObEx form. Table 3-6 shows 520,000 cardiovascular adults whose maximum exposure occurred in the range 9 ppm to 12 ppm under the 1 ExEx standard and 534,000 cardiovascular adults whose maximum exposure occurred in the same range under the 1 ObEx form.

Comparing exposure estimates from the two forms of standard also shows a consistent downward shift in the distribution of exposures when the 1 ObEx form is employed. Each table shows a small number of people at the tail of the distribution who receive higher exposure under the 1 ExEx form of the

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NAAQS. Table 3-2 shows that an estimated 10,200 cardiovascular adults are exposed to CO above 35 ppm (1-hour average) under the 1 ExEx form, whereas none are exposed above this level under the 1 ObEx form. Table 3-5 shows that 98,000 cardiovascular adults are exposed above 12 ppm CO (8-h average) under the 1 ExEx form whereas none are exposed above this level in the 1 ObEx form.

Comparing estimates of COHb levels of cardiovascular adults in Table 3-8 shows that 5,500 adults experience COHb above 2.10 ppm under the 1 ExEx form whereas none experience this level under the 1 ObEx form. While these distributions are different, both sets of estimates show no COHb levels above 2.50.

REFERENCES

1. Johnson, T., and R. Paul. The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide. Prepared by PEDCo Environmental, Inc. for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. EPA-450/5-83-004, December 1983.

2. U.S. Department of Health, Education, and Welfare, Public Health Service. Coronary Heart Disease in Adults. United States: 1960-1962, Vital and Health Statistics Series 11, No. 10, December 1975.

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